A Practical Prediction Method of Hydrodynamic Forces Acting on the Hull of a Blunt-body Ship

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1. INTRODUCTION

MMG model is well-known and widely used in the field of ship maneuverability. However, it can be applied for normal speed, additionally comprehensive captive model tests or some proposed diagrams are necessary to get its hydrodynamic coefficients. Several methods with MMG model have been proposed for ship motion in low speed, such as Kose, Kobayashi and Karasuno, but neither of them has yet been established for general ship. On the other hand, from the practical viewpoint, several methods have been developed to predict hydrodynamic coefficients from ship's principal particulars, such as Kijima and Karasuno. Kijima's model is efficient in predicting ship's maneuverability in initial design stage and is even able to assess the effect of change in stern design. On the other hand, Karasuno's model is efficient in predicting ship's maneuvering motion in relatively large drift angle. Karasuno's model uses theoretical approach and its form also utilizes ship's principal particulars.

The purpose of this paper is to propose a practical method to predict hydrodynamic forces acting on the hull (hereinafter, Hull forces) from normal speed to low speed. It is based on MMG model and predicts the hydrodynamic coefficient for the entire speed range of the ship. It mainly uses Kijima's model for normal speed and Karasuno's model for low speed with relatively large drift motion, therefore the proposed method can be applied to general ship type.

Twenty-one different blunt-body ships are analyzed by the proposed method and a regression model to predict each hydrodynamic coefficient is proposed.

2. PREDICTION METHOD OF HULL FORCES

2. 1 Base calculation of hull forces

This research is based on using Kijima's regression model [1)] and Karasuno's mathematical model [2)]. Hull forces of a ship were calculated with Kijima's and Karasuno's models, these forces are then used as experiment data and further analyzed to predict coefficients proposed in this paper. It is noted that the two models well represent the Hull forces of a ship but over a limited range. To determine the applicable range of these models, experimental data of Esso Osaka were compared with the forces predicted by these models. Fig. 1 shows the values of Y'_H and N'_H obtained from experiment and predicted by Kijima's and Karasuno's models for Esso Osaka. The condition of calculations and experiments are $r'=0$ for left side and $\beta=0$ for right side of Fig.1.

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The calculations of Karasuno's model well represents tendency of experiment data up to 90 degrees of β. The calculations of Kijima's model have more accuracy than those of Karasuno's model for small β. Generally, Kijima's model met well with experiments data below 30 degrees drift angles, and Karasuno's model well described the tendency of overall experiments data.

By means of base data for this research, Kijima's model was used up to 30 degrees of β, Karasuno's model was used for rest of ranges. It is noted that experiments data of X'_H for Esso Osaka have not been published. So the comparison for X'_H is omitted. It is well known that using X_{vr} from Hasegawa chart can be expressed for X'_H in small β and Kijima's model also uses only X_{vr} for expressing X'_H. Calculating with only X_{vr} was used up to 30 degrees of β and Karasuno's model was used beyond 30 degrees of β for the base data of X'_H.

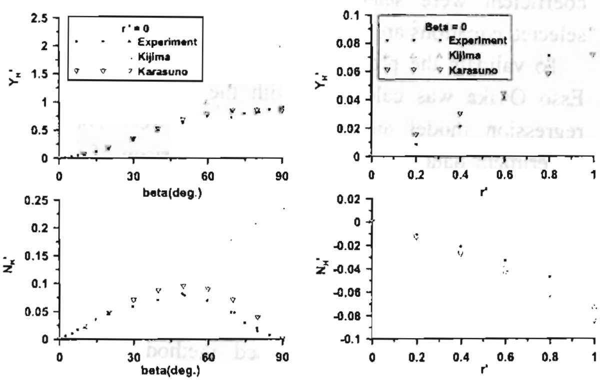

Fig. 1 Comparisons of Y'_H and N'_H

2. 2 Equations of maneuvering ship

The mathematical model of ship's maneuvering motion is based on three degrees of freedom, surge, sway and yaw motion. The equations of the ship maneuvering motion are written as Eq (1).

$$
\begin{aligned}
&(m+m_x)\cdot\dot{u}-m\cdot(v\cdot r+x_G\cdot r^2)=X\\
&(m+m_y)\cdot\dot{v}+(m\cdot x_G+m_y\cdot x_t)\cdot\dot{r}+m\cdot u\cdot r=Y\\
&(I_{zz}+m\cdot x_G^2+J_{zz}+m_y\cdot x_t^2)\cdot\dot{r}+(m\cdot x_G+m_y\cdot x_t)\cdot\dot{v}\\
&+m\cdot x_G\cdot u\cdot r=N
\end{aligned}
\tag{1}
$$

2. 3 Expression of hull forces

To develop and select the equations for Hull forces, the expression ability of equation and its continuity for the overall range of ship's speed is regarded as important. Physical meanings of terms which are components of equations is disregarded. Equations 2-4 are used for expressing Hull forces of a ship. Equation 2 for surge force was developed with above concern. Equations 3 and 4 for sway force and yaw moment are referred from Yumuro's proposal [3].

$$
\begin{aligned}
X'_H &= (\mathrm{ax2}\cdot\sin^2(\beta)+\mathrm{ax4}\cdot\sin^2(2\beta))\cdot\cos(\beta) \\
&\quad +\mathrm{bx1}\cdot\sin(\beta)\cdot r' \\
&\quad +\mathrm{bx2}\cdot\sin(2\beta)\cdot r'\cdot\mathrm{sign}(\cos(\beta))+R(u)
\end{aligned} \tag{2}
$$

$$
\begin{aligned}
Y'_H &= (\mathrm{ay1}+\mathrm{cy1}\cdot r'^2)\cdot\sin(\beta) \\
&\quad +\mathrm{ay3}\cdot\sin(3\beta)+\mathrm{ay5}\cdot\sin(5\beta) \\
&\quad +\left(\mathrm{dy1}\cdot r'+\mathrm{ey1}\cdot r'^3\right)\cdot\cos(\beta)
\end{aligned} \tag{3}
$$

$$
\begin{aligned}
N'_H &= (\mathrm{an2}+\mathrm{cn2}\cdot r'^2)\cdot\sin(2\beta) \\
&\quad +\mathrm{an4}\cdot\sin(4\beta)+\mathrm{dn0}\cdot r' \\
&\quad +\mathrm{en0}\cdot r'^3+\mathrm{dn2}\cdot r'\cdot\cos(2\beta)
\end{aligned} \tag{4}
$$

3. REGRESSION MODEL OF BLUNT-BODY SHIP

Regression model for blunt-body ship is proposed for easy application of above method. Hydrodynamic coefficients for 21 different blunt body ships were calculated using the proposed method. With the calculated hydrodynamic coefficients, the regression models for each coefficient were developed. This model also utilizes parameters for stern hull form, so it is able to express Hull forces correspond to change of stern hull form like Kijima's model.

More than 300 combinations of parameters were tested for each coefficient, and suitable equations for predicting each coefficient were selected from the tested equations. The selected equations are shown in equations 5-7.

To validate the proposed regression model, Hull forces of Esso Osaka was calculated with the proposed method and regression model and the calculations were compared to experiment data. Fig. 2 shows the comparison of sway force and yaw moment. The calculations of sway force met well with experiment data. In the comparison of yaw moment, the calculation did not match with experiment data from 30 to 70 degrees of β. This is because results of Karasuno's model were originally slightly larger than experiment data. Additionally, since the proposed method relies more on Kijima's results for small β, the point of inflexion is shifted further upwards. However entire tendency of yaw moment which was calculated is still reasonable and the calculations well agree with experiment data in small and 90 degrees of β.

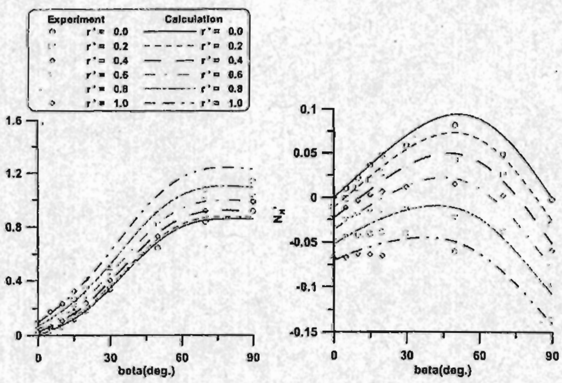

Fig. 2 Comparison between the experiment data and the calculations

It is noted that this regression model are design for blunt-body ship whose C_b is more than 0.75.

$$
\left.
\begin{aligned}
\mathrm{ax2} &= \frac{B}{L}\cdot\left(-0.54867+11.791\cdot\frac{d}{L}\right) \\
\mathrm{ax4} &= k\left(-0.07237-0.52608\cdot\frac{B}{L}\right) \\
\mathrm{bx1} &= 0.01835-1.2425\cdot\frac{d}{L} \\
\mathrm{bx2} &= -0.0333-0.55842\cdot\frac{d}{L}
\end{aligned}
\right\} \tag{5}
$$

$$
\left.
\begin{aligned}
\mathrm{ay1} &= 0.50194+5.3541\cdot\frac{d}{L} \\
\mathrm{ay3} &= -0.08788+0.73174\cdot\frac{C_bB}{L}\cdot K \\
\mathrm{ay5} &= -0.10285+1.9317\cdot\frac{d(1-C_b)}{B}\cdot K \\
\mathrm{cy1} &= k\cdot\left(12.69-131.63\cdot\frac{C_bB}{L}+430.7\cdot\left(\frac{C_bB}{L}\right)^2\right) \\
\mathrm{dy1} &= \frac{B}{L}\cdot(-0.53782+6.6751\cdot k) \\
\mathrm{ey1} &= -0.09165+0.16968\cdot\frac{C_bd}{B}\cdot e_a'
\end{aligned}
\right\} \tag{6}
$$

$$
\left.
\begin{aligned}
\mathrm{an2} &= \frac{B}{L}\cdot\left(0.07093+1.1935\cdot\frac{d}{B}\right) \\
\mathrm{an4} &= K\cdot\left(-0.052545+0.42428\cdot\frac{C_bB}{L}K\right) \\
\mathrm{cn2} &= \frac{d}{B}\cdot\left(-0.14737+0.43812\cdot\frac{d(1-C_b)}{B}e_a'\right) \\
\mathrm{dn0} &= -0.06338-1.253\cdot\frac{d(1-C_b)}{B}\cdot K \\
\mathrm{dn2} &= k\cdot\left(0.46815-0.82503\cdot C_be_a'k\right) \\
\mathrm{en0} &= -0.04755+0.10488\cdot K
\end{aligned}
\right\} \tag{7}
$$

4. CONCLUSIONS

The practical method to predicting Hull forces using Kijima's and Karasuno's model were proposed. The expression ability of Hull forces from low speed to normal speed maneuvering continuously was validated with experiment data.

The regression model which is able to predict hydrodynamic coefficients for the proposed method was also proposed based on the calculation of twenty one blunt-body ships.

REFERENCES

1) K. Kijima and Y. Nakiri: On the practical prediction method for ship manoeuvring characteristics, Trans West Jpn Soc Nav Archit, 105, 2002, pp.21-31.

2) K. Karasuno et al: Predictions of Ship's hull hydrodynamic forces and maneuvering motions at slow speed based on a component-type mathematical model, Proceedings of MARSIM'03, 2003, RC-4

3) A. Yumuro: Some experiments on Maneuvering Hydrodynamic forces in low speed condition, J Kansai Soc Nav Archit 209, 1988, pp.91-101.